Table of Contents

Executive Summary

At the request of the U.S. Department of Energy (DOE), the Electricity Advisory Committee (EAC) puts forward this report on the nation's goal to transform its electric power delivery system (the energy grid) into a more intelligent, resilient, reliable, self-balancing, and interactive network that enables enhanced economic growth, environmental stewardship, operational efficiencies, energy security, and consumer choice. In this report, EAC offers DOE recommendations on how to transform the nation's grid to meet that goal.

While much of the technical and policy discussion on how to ensure a sustainable energy future focuses on energy efficiency, renewable energies, storage, and plug-in electric cars, few emphasize the fact that these solutions all depend on a smarter grid to achieve scale and cost effectiveness. A Smart Grid is foundational for a sustainable energy future; if there is a growing consensus within the United States that clean energy is a platform for rebuilding the American economy, then it follows that a Smart Grid is also critical to economic growth.

This report discusses both the opportunities and challenges the nation faces in its quest to bring the grid into the twenty-first century. Numerous pressures on the electric power delivery system are converging, forcing the system to evolve. These pressures include:

- Global warming
- Rising energy costs
- Rising costs of capital, raw materials, and labor
- Aging infrastructure and workforce
- Continuing national security concerns
- Increasing environmental awareness
- Regulatory pressures
- Social pressures
- Calls for energy efficiency
- Growing demand for energy
- Rising consumer expectations
- Rapid innovations in technology

A Smart Grid can help address these challenges.

There are many working definitions of a Smart Grid and many examples of initiatives under way that could be considered Smart Grid projects. However, for the purposes of this report, the Smart Grid is defined as a broad range of solutions that optimize the energy value chain. To provide examples, this report highlights three utilities deploying various Smart Grid projects that are approved and funded by the relevant regulatory body.

The report substantiates the benefits of moving to a more intelligent grid, not only for utilities and grid operators, but also for consumers and society as a whole. Studies have shown that the economic and environmental payoffs of transforming the current electric power delivery system into a Smart Grid are numerous. From an economic perspective, a Smart Grid can enable reduced overall energy consumption through consumer education and participation in energy efficiency and demand response / load management programs. Shifting electricity usage to less expensive off-peak hours also reduces power disturbance costs and allows for more effective operations and maintenance decisions concerning new construction. From an environmental standpoint, the Smart Grid can reduce carbon emissions by maximizing demand response / load management, minimizing use of peak generation, and replacing traditional forms of generation with renewable sources of generation. A Smart Grid also holds the promise of enhanced reliability and security of the nation's power system.

While there are many benefits, this report also discusses the challenges and barriers the energy sector will face in realizing the Smart Grid. Regulatory challenges center around the need to understand the cost effectiveness of new technologies and systems, appropriate cost recovery, the speed of Smart Grid developments, all while ensuring concrete benefits to consumers. Utility barriers are predominantly those that result from a risk-adverse business environment that is slow to adopt new technology and may open utilities to increased competition. Additional challenges include the lack of consumer understanding of the new technology and its potential benefits, the need for a coordinated framework, and the lack of widely accepted standards for interoperability.

Finally, the report outlines critical steps that DOE can take to help overcome these challenges and fulfill its pivotal and much-needed leadership role in developing a coordinated national Smart Grid strategy. The EAC believes that DOE should not only take on this role, but also guide the development of a national roadmap for achieving the Smart Grid. Further, the EAC recommends that DOE should request appropriations previously authorized by the Energy Independence and Security Act of 2007, create a formal DOE Smart Grid Program office to drive several key roles and functions, and to guide the creation of the educational programs and materials needed by consumers, utilities and regulators and a future Smart Grid workforce.

Chapter 1
Piloting the Smart Grid

Though there has been much debate over the exact definition of a Smart Grid, it actually comprises a broad range of solutions that optimize the energy value chain. Depending on where and how a specific utility operates across that chain, it can benefit from deploying certain parts of the Smart Grid solution set.

Many utilities are in the process of determining the first phases of their Smart Grid plan. Several utilities have received regulator funding and authorization for scale deployments of key elements of Smart Grid, including the examples below. Many of these utilities begin with automatic metering systems, which are logical for utilities because several cost-benefit business cases already exist and regulatory environments typically support these programs. In addition, numerous Smart Grid pilots of varying scale and scope are already testing technology and consumer acceptance. By proving the value of other elements of a Smart Grid, these pilots are helping make the Smart Grid a reality. Some of the other elements include outage and work management systems, substation automation, and remote monitoring of equipment. All of these elements can take advantage of communications systems put in place for automatic metering systems.

1.1 Austin Energy

Austin Energy's Smart Grid initiative initially started out as an enterprise architecture program, followed by an effort to redefine the company's business process using service-oriented architecture (SOA). Austin went on to enable consumer choice through different demand response, distributed generation, and renewable energy programs.[1] These programs saved Austin Energy operational costs, allowing the utility to fund investment in new technologies at no extra cost to consumers. Technology deployment as of August 2008 included 130,000 smart meters and 70,000 smart thermostats. Plans call for an additional 270,000 smart meters and 70,000 smart thermostats, along with 10,000 new transmission and distribution grid sensors, by January–February 2009. At that point, 100% of Austin Energy's consumer base will be served by Smart Grid technologies.

1.2 Southern California Edison

In September 2008, the California Public Utility Commission (CPUC) approved $1.63 billion in funding from ratepayers for Southern California Edison's (SCE's) smart metering program, Edison SmartConnect. SCE will install 5.3 million new smart meters for its residential and small-business customers from 2009 until 2012. SCE has also designed and deployed its own neighborhood electricity circuit, known as Avanti, which delivers power to 1,400 customers. "Much like a household electrical circuit, utility distribution circuits are individual segments of larger power grids that are controlled with on-off switches and protected by circuit breakers. They carry power from neighborhood substations to homes and businesses," SCE said. "During the past five years the company has invested $5 billion in infrastructure expansion to keep pace with a growing service area and to retire

[1] Austin Energy, "Austin Energy – More Than Electricity," Austin Energy, http://www.austinenergy.com (accessed November 2008)..

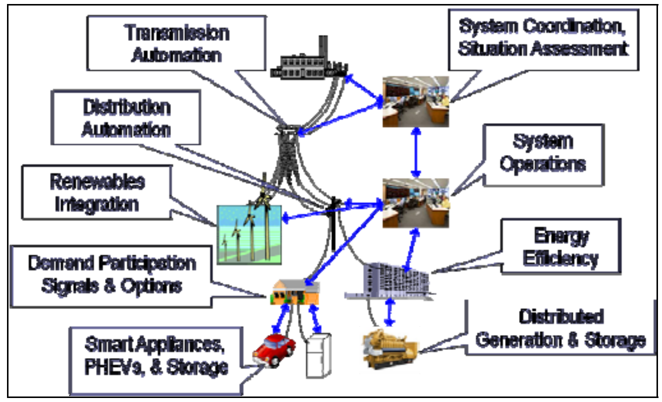
aging components. SCE plans to invest $9 billion during the next five years." [2] In addition, SCE is pursing several grid-connected electro-drive technologies for airports, ports, truck stops, and plug-in electric vehicles.

1.3 ONCOR AND CENTERPOINT

The Public Utilities Commission of Texas (PUCT) approved Oncor's advanced metering system (AMS) plan in August 2008.[4] The plan calls for the installation of more than 3 million advanced meters across Oncor's service territory by the end of 2012 a comprehensive consumer education program and a provision to ensure that the benefits of AMS are available to qualified low-income consumers. The monthly surcharge for residential consumers will be $2.21, and will range from $2.41 to $5.18 for other consumer classes. Oncor also plans to deploy in-home displays as part of its AMS initiative. Through a separate project, Oncor is installing the world's largest clusters of Static Var Compensators (SVCs).[5] SVCs are advanced technology devices that provide high-speed voltage support and significantly increase transmission capacity and efficiency by allowing AC lines to be loaded more heavily without reliability risks. This reduces the need to run generation plants in close proximity to system loads, thereby limiting air pollutants. SVCs will also help control and rapidly respond to changes in grid conditions, and can accommodate wind power and other forms of remote generation. The PUCT also approved a plan by CenterPoint Energy to deploy 127,000 advanced meters in the Houston area.[6] There is currently an active case at the PUCT, Docket No. 35639, to address deployment of advanced meters to the remaining customers in the Houston area.

[2] Southern California Edison, "Avanti: Circuit of the Future," Edison International, http://www.sce.com/Feature/Archive/Avanti.htm (accessed November 2008).
[3] U.S. Department of Energy, *Smart Grid System Report* (Washington, DC: U.S. Department of Energy, 2008).
[4] Oncor/ABB, accessed November 2008
[5] "Oncor to Use New SVC Technology for Grid Reliability," *Transmission and Distribution World*, October 7, 2008, http://tdworld.com/test_monitor_control/highlights/oncor-abb-svc-1008
[6] "Application of CenterPoint Energy Houston Electric LLC for Approval to Implement Advanced Meter Information Network Pursuant to PURA § 39.107(i)," Docket No 35260, August 29, 2008.

Figure 1-1. DOE Smart Grid Components



Source: U.S. Department of Energy 2008.[3]

Figure 1-1 from the DOE *Smart Grid System Report*[7] shows how the many above elements can be incorporated into a Smart Grid.

For more information on the scope of Smart Grid elements and their related applications, please see the *Smart Grid System Report*.

[7] U.S. Department of Energy, *Smart Grid System Report* (Washington, DC: U.S. Department of Energy, 2008).

Chapter 2 Value of a Smart Grid

According to the Galvin Electricity Initiative and the Electric Power Research Institute (EPRI), the economic and environmental benefits of transforming the current electric power delivery system into a Smart Grid are numerous.

A Smart Grid brings the power of networked, interactive technologies into an electricity system, giving utilities and consumers unprecedented control over energy use, improving power grid operations, and ultimately reducing costs to consumers. Using smart meters, utilities can operate more effective demand response / load management programs or charge consumers differentiated rates, especially during peak times when electricity prices are higher. Smart Grid technologies can automatically enable the grid to control specific loads during these critical hours.

2.1 The Economic Case

The EPRI *Electricity Sector Framework for the Future* estimates $1.8 trillion in annual additive revenue by 2020 with a substantially more efficient and reliable grid.[8]

According to the Galvin Electricity Initiative, "Smart Grid technologies would reduce power disturbance costs to the U.S. economy by $49 billion per year. Smart Grids would also reduce the need for massive infrastructure investments by between $46 billion and $117 billion over the next 20 years. [9]

"Widespread deployment of technology that allows consumers to easily control their power consumption could add $5 billion to $7 billion per year back into the U.S. economy by 2015, and $15 billion to $20 billion per year by 2020."[10] Assuming a 10% penetration, distributed generation technologies and smart, interactive storage capacity for residential and small commercial applications could add another $10 billion per year by 2020.[11]

In addition, efficient technologies can dramatically reduce total fuel consumption—and thereby reduce fuel prices for all consumers.

Virtually our entire economy depends on reliable energy. The availability of high-quality power could help determine the future of our economy. (See Table 2-1 for an outline of the value of an enhanced electric power system).

Additionally, the Smart Grid creates new markets as private industry develops energy-efficient and

[8] Electric Power Research Institute, *Electricity Sector Framework for the Future Volume I: Achieving the 21st Century Transformation*, (Washington, DC: Electric Power Research Institute, 2003).

[9] Galvin Electricity Initiative, "The Case for Transformation," Galvin Electricity Initiative, http://www.galvinpower.org/resources/galvin.php?id=27.

[10] Galvin Electricity Initiative, "The Case for Transformation," Galvin Electricity Initiative, http://www.galvinpower.org/resources/galvin.php?id=27.

[11] Galvin Electricity Initiative, "The Case for Transformation," Galvin Electricity Initiative, http://www.galvinpower.org/resources/galvin.php?id=27.

Table 2-1. Value of an Enhanced Electric Power System

	2000	2025		
Parameter	Baseline	Business as Usual (BAU)	Enhanced Electric Power System	Improvement of Enhanced Productivity Over BAU
Electricity Consumption (billion kilowatt-hours [kwh])	3,800	5,800	4,900 – 5,200	10% – 15% reduction
Delivered Electricity Intensity (kwh/$GDP)	0.41	0.28	0.20	29% reduction
% Demand Reduction at Peak	6%	15%	25%	66% increase
% Load Requiring Digital Quality Power	<10%	30%	50%	66% increase
Carbon Dioxide Emissions (million metric tons of carbon)	590	900	720	20% reduction
Productivity Growth Rate (%/year)	2.9	2.5	3.2	28% increase
Real GDP (billions of dollars, 1996)	9,200	20,700	24,300	17% increase
Cost of Power Disturbances to Businesses (billions of dollars, 1996)	100	200	20	90% reduction

Source: Electric Power Research Institute 2003.[13]

intelligent appliances, smart meters, new sensing and communications capabilities, and passenger vehicles.

2.2 The Environmental Case

According to Xcel Energy, "awareness of issues involving greenhouse gases and the promotion of 'green power' has never before been at such a high level in the public consciousness. Utilities are pressured on many fronts to adopt business practices that respond to global environmental concerns. According to a study conducted by the National Renewable Energy Laboratory, if we do nothing, U.S. carbon emissions are expected to rise from 1700 million tons of carbon per year today to 2300 [million tons of carbon] by the year 2030. In that same study, they demonstrate that utilities, through implementation of energy efficiency programs and use of renewable energy sources, could not only displace that growth, but actually have the opportunity to reduce the carbon output to below 1,000 [million tons of carbon] by 2030."[12]

Implementing Smart Grid technologies could reduce carbon emissions by:

- Leveraging demand response / load management to minimize the use of costly peaking generation, which typically uses generation that is comparatively fuel inefficient.
- Facilitating increased energy efficiency through consumer education, programs leveraging usage information, and time-variable pricing.
- Facilitating mitigation of renewable generation variability of output—mitigation of this variability is one of the chief obstacles to integration of large amounts of renewable energy capacity into the bulk power system.
- Integrating plug-in hybrid electric vehicles (PHEVs), distributed wind and photovoltaic solar energy resources, and other forms of distributed generation.

2.3 Benefits to Utilities

Implementing or building a business case for advanced metering infrastructure (AMI) programs is often a utility's first involvement in Smart Grid efforts. Though the terms are not synonymous, the communications technologies and devices in AMI are key enablers of Smart Grid technologies. Advanced meters can better integrate "behind-the-meter" devices such as residential energy storage units, PHEVs, distributed generation, and various mechanisms for controlling or influencing load.

[12] Xcel Energy, *Xcel Energy Smart Grid: A White Paper* (Minneapolis, MN: Xcel Energy, 2008) http://birdcam.xcelenergy.com/sgc/media/pdf/SmartGridWhitePaper.pdf.

[13] Electric Power Research Institute, *Electricity Sector Framework for the Future Volume I: Achieving the 21st Century Transformation* (Washington, DC: Electric Power Research Institute, 2003).

In the industry push for Smart Grid upgrades, utilities are faced with the desire to enhance technology while maintaining the reliable and safe infrastructure needed to serve their consumers today. They must balance wholesale replacement of technology with the practicality of tactical upgrades. Utilities will need to be open to supporting the needs of an increasingly complex group of consumers with sophisticated business, technology, and environmental objectives.

Improved Reliability

According to the Galvin Electricity Initiative, "the U.S. electric power system is designed and operated to meet a '3 nines' reliability standard. This means that electric grid power is 99.97% reliable. While this sounds good in theory, in practice it translates to interruptions in the electricity supply that cost American consumers an estimated $150 billion a year."[14]

A major blackout is even more costly. EPRI estimates $1 billion in direct costs and socioeconomic impacts. Reducing a major cascading outage by only half would result in savings in excess of millions of dollars annually.[15] Table 2-2 shows the average estimated cost of a one-hour power interruption.

Table 2-2. Cost of One-Hour Power Service Interruption in Various Industries

Industry	Average Cost of 1-Hour Interruption
Cellular communications	$41,000
Telephone ticket sales	$72,000
Airline reservation system	$90,000
Semiconductor manufacturer	$2,000,000
Credit card operation	$2,580,000
Brokerage operation	$6,480,000

Source: Galvin Electricity Initiative 2008.[16]

The Galvin Electricity Initiative says that "in an increasingly digital world, even the slightest disturbances in power quality and reliability cause loss of information, processes and productivity. Interruptions and disturbances measuring less than one cycle (less than 1/60th of a second) are enough to crash servers, computers, intensive care and life support machines, automated equipment and other microprocessor-based devices."

In addition, Galvin explains the situation may worsen as the nation's electric infrastructure continues to age. "In the United States, the average power generating station was built in the 1960s using technology that is even older. The average age of a substation transformer is 42 years, but the transformers today were designed to have a maximum life of 40 years."[17]

The Smart Grid enables significant improvements in power quality and reliability. Smart meters will allow utilities to confirm more easily that meters are working properly. Two-way communications all across the grid will let utilities remotely identify, locate, isolate, and restore power outages more quickly without having to send field crews on trouble calls. In fact, a Smart Grid could eliminate up to 50% of trouble calls.[18]

Through proactive grid management and automated response, the frequency and duration of power outages can be reduced, which will result in fewer anxious calls to utility call centers and improved consumer satisfaction. Remote monitoring and control devices throughout the system can create a "self-healing" grid, which can restore and prevent outages and extend the life of substation equipment and distribution assets. Through such automation, rising consumer expectations for power quality and reliability can be met in the face of growing electricity demand and an aging infrastructure and workforce.

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[14] Galvin Electricity Initiative, "Fact Sheet: The Electric Power System is Unreliable," Galvin Electricity Initiative, http://www.galvinpower.org/resources/galvin.php?id=26

[15] Electric Power Research Institute, "39 Grid Operations," *2008 Portfolio* (Washington, DC: Electric Power Research Institute, 2008), http://mydocs.epri.com/docs/Portfolio/PDF/2008_P039.pdf.

[16] Galvin Electricity Initiative, "Fact Sheet: The Electric Power System is Unreliable," Galvin Electricity Initiative, http://www.galvinpower.org/resources/galvin.php?id=26

[17] Galvin Electricity Initiative, "Fact Sheet: The Electric Power System is Unreliable," Galvin Electricity Initiative, http://www.galvinpower.org/resources/galvin.php?id=26

[18] Tom Standish, "Visions of the Smart Grid: Deconstructing the traditional utility to build the virtual utility" (Washington DC: U.S. Department of Energy 2008 Smart Grid Implementation Workshop, June 19, 2008), Keynote address.

Deferred capital spending for generation, transmission, and distribution investments

By reducing peak demand, a Smart Grid can reduce the need for additional transmission lines and power plants that would otherwise be needed to meet that demand. The peak usage of the California Independent System Operator (CAISO) for 2005–2006, for example, is 50,085 megawatts (MW). However, usage exceeds 45,000 MW only 0.65% of the time annually.[19] This means that California must build peaking plants, additional transmission lines, distribution lines, and possibly even additional baseload power plants to generate enough supply to meet demand that occurs less than 1% of the time. The ability to reduce peak demand via Smart Grid-enabled consumer demand response / load management can defer or reduce the need to build resources that would be unused much of the time. A Smart Grid can also defer capital investments by prolonging the life of existing assets through enhanced asset management methodologies that exploit additional condition monitoring and diagnostic information about system components.

Reduced operations and maintenance costs

Smart Grid technologies allow for remote and automated disconnections and reconnections, which eliminate unneeded field trips, reduce consumer outage and high-bill calls, and ultimately reduce operations and maintenance (O&M) costs. Reduced costs can also result from near real-time remote asset monitoring, enabling utilities to move from time-based maintenance practices to equipment-condition-based maintenance. Using enhanced information about grid assets from Smart Grid monitoring technologies, grid operators can reduce the risk of overloading problematic equipment—especially transmission power transformers. These multi-million dollar assets have an expected life of 40 years, but a significant percent of the U.S. power transformer fleet is approaching or already past this age. Simply keeping the transformers in service risks increased failure rates and even greater outage costs, as well as larger disruptions or more severe damage to system equipment. However, doing so is often a necessity, as the cost of replacing transformers has increased rapidly, along with the prices for copper and ferromagnetic steel. Today, multi-function sensors are available that can continuously monitor a number of physical parameters for signs of incipient failure (e.g., insulation breakdown, loosening of fasteners that hold windings in place, etc.). Information from these devices, together with sophisticated analysis of fault conditions from power circuit breakers that protect the transformers, can help determine when the equipment needs maintenance, repairs, and eventually replacement.

Increased efficiency of power delivery

Up to a 30% reduction in distribution losses is possible from optimal power factor performance and system balancing.[20] Today, this problem is managed to some extent by controlled or automated capacitor banks on distribution circuits and in substations. Control of these devices can be greatly improved with better real-time information. Almost all higher efficiency appliances, heating, ventilation, and cooling (HVAC) systems, consumer electronics, lighting and other load devices are changing from being "resistive" (e.g., incandescent light bulbs) or "rotating" (as in motors) to "inverter based." The transition of load from "resistive" to "inverter based" means that the overall system performance, especially with respect to power factor and reactive power needs, changes dramatically over time. Smart Grid technologies offer utilities increased monitoring of rapid power changes and help them adapt control schemes and deploy capacitors and other power-factor control devices—including power electronics-based devices in substations—to compensate.

Integration of renewable energy and distributed resources

Smart Grid technologies will allow the grid to better adapt to the dynamics of renewable energy and distributed generation, helping utilities and consumers more easily access these resources and reap the benefits. Today's grid was designed to move power from centralized supply sources to fixed, predictable loads; this makes it challenging for the grid to accept input from many distributed energy resources across the grid. And because resources such as solar and

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[19] Jim Detmers, "CAISO Operational Needs from Demand Response Resources," (California Independent System Operator, November 2006), Powerpoint slides, http://www.caiso.com/18a1/18a1ec276b6a0.pdf.

[20] Xcel Energy, *Xcel Energy Smart Grid: A White Paper* (Minneapolis, MN: Xcel Energy, 2008) http://birdcam.xcelenergy.com/sgc/media/pdf/SmartGridWhitePaper.pdf.

wind power are intermittent, the grid will require integrated monitoring and control, as well as integration with substation automation, to control differing energy flows and plan for standby capacity to supplement intermittent generation. Smart Grid capabilities will make it easier to control bi-directional power flows and monitor, control, and support these distributed resources.

Improved System Security

Utilities are increasingly employing digital devices in substations to improve protection, enable substation automation, and increase reliability and control. However, these remotely accessible and programmable devices can introduce cyber security concerns. While the North American Electric Reliability Corporation (NERC) has developed Critical Infrastructure Protection standards to address these issues, Smart Grid technology and capabilities will offer better integration of these devices, increased use of sensors, and added layers of control. Smart Grid technologies, however, can bring their own cyber security concerns, which will require comprehensive, built-in security during implementation. Smart Grid technologies can do the following:

- Bring higher levels of investment and greater penetration of information technology (IT) into the grid, allowing utilities to address cyber security issues more effectively.
- Increase the robustness of the grid to withstand component failures, whether due to natural events, age/condition of assets, or hostile causes.
- Allow grid components and IT systems in time to detect intrusion attempts and provide real-time notification to cyber security organizations.

Table 2-3 elaborates on the benefits of specific Smart Grid generation technologies, while Table 2-4 outlines the benefits of specific Smart Grid transmission and distribution (T&D) technologies.

2.4 Benefits to Consumers

A 2007 survey conducted by IBM of 1,900 energy consumers revealed that growing reliability concerns, fears over environmental sustainability, and increasing costs of energy bills have created a demand from consumers for more control over their energy consumption decisions.[21] As Smart Grid projects enable a more participatory network comprising intelligent network-connected devices, distributed generation, and energy management tools, consumers will be able to better plan and manage their energy consumption.[22] Additional benefits are outlined below.

Consumption Management

Smart Grid technologies offer consumers the knowledge and ability to manage their own consumption habits through in-home or building automation. Advanced meters tell consumers how energy is used within their home or business, what that usage costs them, and what kind of impact that usage has on the environment. They can manage their usage interactively or set preferences that tell the utility to automatically make adjustments based on those choices. Consumers can create home area networks (HANs) of smart appliances, thermostats, security systems, and electronics that are able to communicate with the grid and relay information back to the consumer. Consumers will further be able to remotely manage these appliances. Two-way communications facilities will even allow appliances and security systems to initiate the conversation, notifying home and business owners of problems or safety alerts when they are away. These Smart Homes and Smart Buildings are convenient, efficient, and can encourage consumers to make energy-efficient decisions that result in energy savings.

Cost Savings from Peak Load Reduction

The electric power industry has long known that demand response / load management programs aimed at reducing peak load can have economic benefits for the utility and the consumer. As noted in the Electricity Advisory Committee's report, *Keeping the Lights On in the New World*, some peaking combustion turbines only run a few hours a year when load is at its highest, which in a market environment can mean that energy costs $1000 per megawatt hour (MWh) to generate.[23] In a regulated environment, the system average costs still have to cover the annualized cost for those units, even if it does not

[21]

[22] Xcel Energy, *Xcel Energy Smart Grid: A White Paper* (Minneapolis, MN: Xcel Energy, 2008) http://birdcam.xcelenergy.com/sgc/media/pdf/SmartGridWhitePaper.pdf.

[23]

Table 2-3. Benefits of Generation Smart Grid Technologies

Application	Definition	Benefit	Benefit as % of System Wholesale Energy Costs	Power Requirement (Max)	Duration Requirement	Other Requirement	Structural Issues	Comments
Governor response	Generator autonomous dynamic response to frequency	Renewables typically lack governor response, which is essential for system stability. Increasing conventional unit governor response for renewables will impact the markets.		1%–5% of associated generation	Seconds to a few minutes	Sub-second response	None; standards for renewable governor response are lacking.	This is an unexplored area.
Regulation	Second-by-second adjustment of power production to match load and schedules and regulate system frequency	Regulation is a defined ancillary service with annual costs to markets on the order of millions of dollars. Storage can displace conventional fossil generation for this purpose and free up generation capacity for energy production. Renewable generation typically lacks regulation capability.	0.2%–0.5%	Typically 1%–2% of system peak overall	Studies show that 15–30 minutes duration is required to be effective.	Rapid (<10 second) response	In many markets, regulation often overlaps short-term balancing energy. Control algorithms can be adjusted to exploit fast storage response and use storage first for regulation.	Ancillary markets are already a target of merchant storage. Charging losses must be paid in balancing markets so efficiency is a key.
Balancing energy/real-time dispatch	Adjustment of production economically/market based on a minute-by-minute basis to match demand	In some markets, hourly schedule changes cause "spikes" in balancing requirements and prices. Storage used for this purpose would mitigate the spikes. Renewable volatility is expected to greatly increase balancing energy needs, which would	2%–3%	Balancing is typically 2%–3% of system energy today, and may double with large renewable penetration.	1 hour or more	Charge efficiencies must be settled in the real-time markets, so efficiency becomes an important attribute.	None; standards for renewable governor response are lacking.	Another target of merchant storage; short-term price arbitraging.

Application	Definition	Benefit	Benefit as % of System Wholesale Energy Costs	Power Requirement (Max)	Duration Requirement	Other Requirement	Structural Issues	Comments
		increase prices and reduce capacity available for base/scheduled energy production; storage can mitigate this problem.						
Reserve augmentation	Conventional generation provides spinning and operating reserve as backup against the failure of resources.	Storage can provide short-term reserves and enable slower generation to participate, freeing up additional capacity from economic units on line.	5%	Spinning reserve is typically matched to the largest unit in a control area or congestion zone; typically 1000–1500 MW.	15–30 minutes if backed up by slower generation.	Storage must be kept in a state of charge in order to supply reserves.	Unexplored territory except for hydroelectric resources	
Intra-day production shifting	Some renewable resources have intra-day behavior (e.g., mountain wind locations) which impose scheduling and load matching challenges.	Storing renewable production for several hours will utilize more renewable energy and reduce peak fossil production.		Depends upon specific resources; could be a range of 30%–50% of resource maximum power capacity.	Hours	Energy capacity has to be economic against the value of energy captured.	None	
Diurnal renewable levelizing	Diurnal renewable levelizing	Storing renewable resources from daily peak production for use at peak load hours.		Can be as much as 50% of renewable resource production.	6–12 hours	Energy capacity has to be economic against the value of energy captured.	None	
Weekly production levelizing	Weekly production levelizing	Store production on weekends for weekday use.		Can be 20%–30% of peak load for two days.	48 hours			Typical pumped hydro application
Seasonal production levelizing	Seasonal production levelizing	Store seasonal resources for use in peak load seasons.			Months			Typical hydroelectric function

Table 2-4. Benefits of Transmission and Distribution Smart Grid Technologies

Application	Benefit	Quantification	Power Requirement	Duration	Issues	Comments
Transmission capacity factor for renewables	Capture renewable production and deliver when transmission capacity is available	20%–50% of renewable capacity	20%–30% of renewable peak production.	6–12 hours	Uncertain long-term economics as capacity is built	Economic issue for wind developers today
Transmission congestion relief	Generalized application of above		Equal to typical congested power on path.	Hours	Uncertain long-term economics as capacity is built	Likely to grow in importance
Transmission reliability limit relaxation	Specialized technical version of congestion relief relying on very fast storage	Tens of millions to 100 million dollars	100–1000 MW	Seconds to 15 minutes	Unexplored and will need rigorous analysis and demonstration	Would be backed up by quick-start reserve in some cases
Transmission capital deferral	Relieve short-term congestion			Hours	Very site specific	Similar to congestion relief
Substation peak load/backup	Defer transformer upgrades (and other upgrades) due to peak load growth	$1 million per station for 2–5 years deferral	2–10 MW	Hours	Economics unanalyzed	Links to loading issues around distributed generation penetration
Voltage support						
Reliability enhancement	Provide down-circuit supply while outages restored		2–10 MW	Hours	Economics unanalyzed	Alternative to switching on long rural circuits

show up as a very high spot price. Consumers that defer peak energy usage to a later hour or otherwise reduce peak consumption save the cost of generating expensive peak energy. All consumers either benefit from reduced peak prices in a market environment, or from reduced average costs in a regulated environment. Peak reduction is thus a highly leveraged win for all consumers. In the longer term, the use of demand response / load management programs as a generation resource avoids building expensive peak generation. The Smart Grid is a key enabler in achieving demand response / load management; communicating peak prices to consumers; and integrating smart appliances, consumer storage and distributed generation, and smart building controls with the goal of peak reduction.

Convenience of distributed generation

The new energy paradigm does not just empower utility consumers to better manage their consumption, reduce demand, and help the environment; through distributed generation, it can enable them to become energy producers. Distributed generation assets are typically consumer owned, and rely on a range of generation technologies that deliver electricity directly to the consumer. Onsite photovoltaic panels and small-scale wind turbines are familiar examples. Emerging distributed generation resources include geothermal, biomass, carbon-free hydrogen fuel cells, PHEVs, and batteries for energy storage. As the cost of traditional energy sources continues to rise and the cost of distributed generation technologies declines, these new energy resources will become more affordable. Renewable energy resources are not only environmentally friendly; they create cost-saving opportunities for consumers who are able to generate electricity in excess of their own needs and sell the surplus back to the grid.

Cost Savings through Energy Efficiency

Today's new smart metering and communications technology could enable consumers and system operators to monitor and potentially control consumption—and cost—at 15-minute intervals. Such improved awareness gives consumers incentives to reduce energy use by switching to more efficient appliances and light bulbs, adjusting thermostat temperatures, and turning off lights and other energy-consuming devices when not in use. Consumers will become more active participants in the energy market, as they will be able to more easily compare monthly bills applying different electric retailers' rates to their actual usage. Improved market transparency will allow consumers to easily seek the best retail prices and services. Based on nationwide pilot data, consumers could reduce their electricity consumption by up to 25% during peak periods.[24]

Convenience of Advanced Meters

With two-way communications between the consumer's meter and the utility, automated meter reading is much easier for consumers and utilities alike. Not only are digital smart meters more accurate, but they also will greatly reduce the number of estimated readings due to inaccessible meters. Smart Grid technologies will also allow utilities to connect and disconnect electric service remotely, making it easier and faster for consumers to start, stop, or transfer service, as well as change retail electric providers.

Reduced Industrial Consumer Costs

Commercial and industrial consumers will benefit greatly from a Smart Grid. For example, motors account for about 65% of industrial electricity usage. Small improvements in motor efficiency can therefore generate significant savings in energy costs. A U.S. motor challenge study indicated that 85 billion kWh per year could be saved using alternating current (AC) drives and high-efficiency motors.[25] Moreover, only a small percentage of large motors are controlled by variable speed drives. Most simply run at full speed all the time. Energy consumption of motors varies with the square of the speed; a centrifugal pump or fan running at 80% speed consumes only half of the energy required when running at full speed. Thus, a variable speed drive can reduce a motor's energy consumption by as much as 60%.[26] Further, a variable speed drive can be enabled to respond automatically to pricing signals from the utility; this could have a major impact on a firm's total consumption requirements and costs, as well as energy-efficiency benefits for society.

Enhanced Business Consumer Service

According to EPRI,[27] the Smart Grid will allow automatic monitoring and proactive maintenance of end-use equipment, which can be an avenue for energy savings and reduced carbon emissions. Equipment is sometimes not properly commissioned when it is first installed or replaced. With the two-way communications of a Smart Grid infrastructure in place, a utility could monitor the performance of major consumer equipment through advanced interval metering and on-premise energy management control systems. The utility would thus be able to advise the consumer on the condition of specific facilities. EPRI estimates that this could lead to an annual energy savings potential of 2.2 billion–8.8 billion kWh, depending on the level of market penetration.[28]

Research from Energy Insights, an IDC Company, indicates that consumers are interested in the opportunities offered by the Smart Grid. Results from the 2007 Energy Insights *National Residential Online Panel In-Home Display Survey* found that most people surveyed are interested in having such a unit to provide direct feedback on their energy use. About 70% expressed high interest, with an additional 20% expressing moderate interest. Although consumers are less enthusiastic about giving their utility control over their appliances, a third said they would be more likely to sign up for a dynamic pricing program if their utility could use the in-home display to automate their appliances.[29]

Findings from Energy Insights' *2008 National Residential Online Panel Real-Time Pricing (RTP) Survey* show that a large group of consumers is interested in RTP.[30] Results from Ameren's Energy-Smart Pricing Plan (ESPP) pilot in Illinois and its subsequent Power Smart Pricing program also prove that consumers can and will respond to price signals; in fact, participants significantly reduced both their peak demand and energy consumption.[31]

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26 ABB, *Pathway for Transmission & Distribution Sector*, a report submitted to the Business Roundtable Energy Task Force, 2006.

27 EPRI, Green Grid Report, 2007.

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Table 2-5. End-User Benefits from Smart Grid Technologies

Application	Benefit	Quantification	Power Requirement	Duration	Comments
Storing renewable distributed generation production	Capture renewable DG production for use when wanted and reduce grid consumption; mitigate capacity charges as well		Equal to local DG peak production	Hours	
Time shifting of demand to avoid peak prices	Avoid high real-time prices at peak		Equal or less than peak load	Hours	
Price arbitraging in real-time pricing situation	Same as for storage in generation balancing energy		As desired	30 minutes	Not allowed under existing tariffs
Reliability enhancement	Avoid interruptions	Linked to value of production and cost of interruption	Equal to peak load protected	Minutes to hours	Linked to DR and backup generation
Utility reliability enhancement	Allow utility control for targeted enhancement	Linked to utility capital deferral	Equal to peak load typically	Minutes to hours	Unexplored, but potentially attractive in urban situations
PHEV integration	Lower cost of charging by only using off peak power	Lower cost of driving, plus utility capital deferral	Equal to vehicle power draw	Hours	
Demand response / load management integration	Make DR participation in markets more attractive			Minutes to hours	Commercially being investigated today
Renewable demand response / load management	Renewable volatility and difficulty of control make them unreliable for demand response applications. Storage can be an enabler.				
Railroad acceleration support	Avoid significant catenary resistive losses	Being investigated today	Being investigated today	Being investigated today	Being investigated today

Table 2-6. Smart Grid Benefits Matrix

Potential and Real Benefits to be Realized by Building and Implementing a Smart Grid						
Benefit	**Stakeholder**					
	Utility	**Independent Generator**	**Residential**	**Commercial**	**Industrial**	**Future Generations**
System Reliability and Economics						
Smart Grid technologies allow faster diagnosis of distribution outages and automated restoration of undamaged portions of the grid, reducing overall outage times with major economic benefits.	X		X	X	X	
Smart Grid's automated diagnostic and self-healing capability prolongs the life of the electric infrastructure.	X					X
Distributed generation is supported because the grid has the ability to dynamically manage all sources of power on the grid.	X	X	X	X	X	X
Price-sensitive peak shaving defers the need for grid expansion and retrofit.	X					
Price-sensitive peak shaving reduces the need for peaking generation capacity investments.	X		X	X	X	
Smart Grid technologies may allow better utilization of transmission paths, improving long distance energy transfers.	X	X				
Positive Environmental Impact						
Smart Grid can reduce distribution losses, thus reducing power generation demands.	X		X	X	X	X
Grid integration of high levels of renewable resources as called for in many state RPS standards will require Smart Grid to manage extensive distributed generation and storage resources.	X	X	X	X	X	X
A high penetration of PHEV will require Smart Grid to manage grid support of vehicle charging. Potential use of PHEV as Vehicle to Grid will absolutely require Smart Grid technologies.	X		X			X
A Smart Grid enables intelligent appliances to provide feedback through the system, sense grid stress, and reduce their power use during peak demand periods.	X		X			
Advanced metering technology can be used to help measure electricity use and calculate the resulting carbon footprint.			X	X	X	X
Increased efficiency of power delivery						
Direct operating costs are reduced through the use of advanced metering technology (AMR/AMI) such as connects/disconnects, vehicle fleet operations and maintenance, meter reads, employee insurance compensation insurance, etc.	X					
Smart Grid technologies, such as synchrophasors, offer the promise of reducing transmission congestion.	X	X	X	X	X	
Economic Development						
Standards and protocols supporting interoperability will promote product innovation and business opportunities that support the Smart Grid concept.	X	X	X	X	X	X
Consumer Choice						
Provide consumers with information on their electric usage so they can make smart energy choices.			X	X	X	X
Real-time pricing offers consumers a "choice" of cost and convenience trade-offs that are superior to hierarchical demand management programs.			X	X	X	
Integration of building automation systems offers efficiency gains, grid expansion deferral, and peak shaving.	X			X		

Chapter 3 Challenges and Opportunities

"The biggest impediment to the smart electric grid transition is neither technical nor economic," said Kurt Yeager, Executive Director of the Galvin Electricity Initiative and President Emeritus of EPRI, in testimony before the House Committee on Energy and Commerce on May 3, 2007. "Instead, the transition is limited today by obsolete regulatory barriers and disincentives that echo from an earlier era." Those regulatory barriers and other challenges to the Smart Grid are discussed in detail below.

3.1 Regulatory Challenges

The nation's electric power delivery system is much like the telecommunications network of the past—dated and increasingly costly for consumers. Three decades ago, one phone company was the monopoly provider of services across much of the United States, and it was illegal to plug other companies' telephones and devices into that company's network. Today, telecommunications choices and services are much greater thanks to legislation and technological advances that broke up the monopoly and later opened the door to competition in the telecommunications industry. The Energy Independence and Security Act of 2007, with its support for Smart Grid research and investment, is an important step forward in achieving similar results for the power industry, although more government involvement is needed to remove obstacles to further innovation.[32]

State public utility commissions (PUCs) are responsible for ensuring that electric utilities under their jurisdiction provide safe and reliable service at a reasonable price. PUCs analyze and determine if proposed utility infrastructure investments, like the deployment of the Smart Grid, are prudent investments. Investments are often evaluated based upon actual and realizable benefits, and while future benefits may be considered, they must be evaluated appropriately. The state-by-state PUC approval process could create a patchwork approach, as different Smart Grid improvements could be adopted by neighboring states or even utilities within one state. PUCs need also to develop unique rate structures using Smart Grid technology by creating special time-of-use rates, whether hourly, critical peak pricing, or some other modification from the existing approaches.

As technology advances and as the nation approaches the building of a Smart Grid, consumers and utilities will have a greater opportunity to control their electric consumption in response to price and system conditions.

[32] Galvin Electricity Initiative, "Fact Sheet: The Path to Perfect Power: Policy Solutions," Galvin Electricity Initiative, http://www.galvinpower.org/files/PolicyPriorities4.pdf.

3.2 Utility Business Model

Many of today's utility business models are based upon the utility earning a negotiated return on prudent capital investments. It is not surprising, therefore, that the utilities responsible for making prudent investments focus on minimizing risk. Consequently, utilities are often slow to adopt new technologies that have not been extensively proven outside of a laboratory. In general, the existing utility business model does not provide economic rewards for cutting-edge utilities. In addition, the value of Smart Grid technologies has been difficult to quantify in a simple cost-benefit analysis due to the multi-tiered benefits they provide to the utility, the consumer, and society. Comparative financial metrics are difficult to achieve because each utility incorporating Smart Grid technologies has put a unique level of investment in a variety of technologies, as shown in the Chapter 2 examples. In turn, the rewards—financial, operational, experiential, and otherwise—for first adopters are not generally recognized by other electric industry stakeholders. Existing electric rate structures create further complications. As the Smart Grid enables more conservation and distributed generation, regulators may have to address the problem of how to provide appropriate rewards to utilities for actions that will reduce total electricity sales.

3.3 Lack of a Coordinated Strategy

The efficient evolution to a Smart Grid will require a coordinated strategy that relies upon building an appropriate electric infrastructure foundation to maximize utilization of the existing system. The Smart Grid is a new integrated operational and conceptual model for utility operations. Among other things, it envisions the real-time monitoring of all utility transformers, transmission and distribution line segments, generation units, and consumer usage, along with the ability to change the performance of each monitored device. This will require significant planning for both implementing a system-wide installation of monitoring devices (including monitoring devices at the consumer level), and for installing the equipment necessary to enable parts of the system to "talk" with other components and take rerouting, self-healing, and other actions independent of system operators. Developing such an integrated system requires a multi-year, phased installation of Smart Grid devices and upgraded computer and communication capabilities; those investing in this technology likely will not realize the value until the return value of the combined benefits of these technologies are achieved.

3.4 Cost

As discussed, the effort to move from using smarter technology to a Smart Grid is a significant undertaking that needs focused coordination both strategically and tactically. This undertaking also will require significant investment. Investors often face the challenges of access to capital to make these investments, as well as the lack of ability to bear the associated costs of the expenses. Utilities must grapple with making Smart Grid investments, knowing that significant utility and consumer benefits may not occur for several years. The Smart Grid is a complex, comprehensive, and integrated monitoring and operating system; it will provide publicly observable benefits only after considerable investments have been made in upgrading the infrastructure of the nation's utilities and the monitoring and control devices in the homes and businesses of consumers. Investing in equipment and personnel training, for which there are few short-term benefits, creates operating costs that may be difficult to justify without policy direction and support from government agencies.

3.5 Consumer Impacts

Intellectually, Americans can welcome a Smart Grid because it offers more efficient use of resources, while maximizing electricity services. However, in order for the typical consumer to accept and embrace the transformation to a Smart Grid, utilities and policymakers must communicate the benefits effectively to the public. Consumer benefits need to be defined and advocated by utilities and policymakers alike across all economic levels in order to overcome this hurdle.

3.6 Key Infrastructure Issues

Without question, creating a Smart Grid presents many complex technical challenges. Chief among them are the integration issues associated with the automation systems that manage the nation's transmission and distribution networks, along with the interface codes and standards required to enable a more reliable and smoothly operating electric system. One of the most important foundations of a Smart

Grid is the interoperability that enables all of the required devices, technologies, and agents (for example, energy producers, consumers, and operators) to interact beneficially in the network.

Interoperability has been defined as the ability of two or more systems or components to exchange information and to use the information that has been exchanged.[33] In the case of the Smart Grid, these systems might include outage management, distribution management, condition-based maintenance, supervisory control and data acquisition (SCADA), AMI, distribution planning, load forecasting, and a variety of systems that have not been designed or built yet.

Ultimately, when a new device is added to the system, interoperability will enable it to register itself in the grid upon installation, communicate its capabilities to neighboring systems, and cause the connectivity database and control algorithms to update themselves automatically.

Evidence from other industries indicates that interoperability generates tangible cost savings and intangible benefits amounting to 0.3%–4% in cost savings or avoided construction. In the electric power industry, that could result in a net benefit of up to $12.6 billion per year.[34]

The Smart Grid will require interoperability among the many technology components involved. New solutions must also be configured to exchange information with legacy systems, including existing back office systems and other systems that need to be connected.

The past 20 years have seen tremendous progress in collaborative efforts across the industry to address issues associated with interoperability. The various GridWise organizations (American National Standards Institute, Electric Power Research Institute, International Electrotechnical Commission, Institute of Electrical and Electronics Engineers, National Rural Electric Cooperative Association, and others) have created a knowledge base to draw upon and an initial set of standards and models the industry can implement. Common Information Model (CIM), IntelliGrid Architecture, MultiSpeak, Telecontrol Application Service Element 2 (TASE-2), Utility Communications Architecture (UCA) and the GridWise Architecture Council concepts all contain valuable knowledge to assist utilities and integrators in achieving interoperability. Industry support for continued development in several areas could significantly improve the potential state of interoperability, thereby improving the cost-benefit ratio of deploying a Smart Grid.[35]

3.7 SECURITY

The vision of the Smart Grid typically boasts enhanced system security. Indeed, the report *A Systems View of the Modern Grid*, published by DOE and the National Energy Technology Laboratory (NETL) in January 2007 includes "resists attack" as one of seven principal characteristics of the future Smart Grid.[36] The DOE report goes on to list the following design features and functions:

- Identification of threats and vulnerabilities
- Protecting the network
- Inclusion of security risk in system planning

Expected benefits include:

- Reduced system vulnerability to physical or cyber attack
- Minimal consequences of any disruption, including its extent, duration, or economic impact
- Using security-related improvements to also help optimize reliability, communications, computing, decision-making support and self-healing

However, many of the technologies being deployed to support Smart Grid projects—such as smart meters, sensors, and advanced communications networks—can themselves increase the vulnerability of the grid to cyber attacks. Accordingly, it is essential that Smart Grid deployment leverage the benefits of increased threat awareness while mitigating against heightened security concerns. It will be a difficult task, but one that can be addressed by being aware of the risks and leveraging security best practices from other industries.

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[34] Rick Drummond, "Why Interoperable Grid Software will Pay for Itself," *Smart Grid Newsletter*, June 20, 2007, http://www.smartgridnews.com/artman/publish/article_210.html.

[35] Subramanian V. Vadari, Wade P. Malcolm, and Mark Lauby, "Resolving Intelligent Network Interoperability Challenges" (Accenture and NERC)

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3.8 Credit Crisis Impacts

The 2008 global financial crisis has dealt a major blow to business and consumers alike. In September 2008, Constellation Energy Group, Inc. (Constellation) was acquired by MidAmerican Energy Holdings for $4.7 billion after its stocked plunged 60% over the preceding three days on fears about the company's exposure to bankrupt Lehman Brothers and its overall liquidity situation. Two weeks later, Reliant Energy (Reliant), after its stock nose-dived on news that it was losing a credit arrangement with Merrill Lynch and was raising $1 billion in new, more expensive capital, announced that it had formed a special committee to review strategic alternatives.

Despite media attention to the precarious financial situation of Constellation and Reliant, the majority of U.S. investor-owned utilities are vertically integrated and dominated by their regulated operations. These companies have little or no credit risk from trading or hedging activities and are unlikely to fall victim to the problems that beset Constellation and Reliant. Nonetheless, some analysts believe that technology spending will slow in the near term as utility chief information officers conserve cash by freezing or slowing down all external spending, primarily due to the tight commercial paper market which has made short-term cash difficult and costly to raise.[37] Over the next one to two years, the credit crisis will probably make the cost of capital more expensive, even for utilities with good credit ratings. At the same time, state utility regulators are becoming increasingly reticent to approve large capital expenditures, given the existing risks associated with the rising costs of labor and materials, the uncertainty surrounding the cost of carbon regulation in an inevitable mandatory carbon cap-and-trade program in the U.S. (at least for fossil fuel plants), and the unknown impact of a recession on demand growth. The credit crisis means that utilities in some jurisdictions may delay raising capital to build new large power plants and transmission lines, which can cost billions of dollars.

Despite this expected slowdown in spending for large capital projects, energy demand will continue to grow (albeit at a slower rate) and state utility regulators will continue to enforce renewable-energy, CO_2-reduction, and energy-efficiency goals. This situation will make distributed energy, demand response / load management programs, and energy-efficient technology investments more attractive, particularly in light of the Emergency Economic Stabilization Act of 2008. Tucked into the $700 billion rescue legislation is a measure allowing utilities to quickly write off investments in smart meters or other Smart Grid equipment. Worth $915 million over 10 years, the tax treatment in this legislation allows companies to depreciate investments over 10 years instead of 20 years, in essence taking bigger deductions each year. As a result, spending on renewable energy, distributed energy, smart metering, and Smart Grid-related technologies is likely to increase over the next one to two years.[38]

3.9 Conclusion

The Smart Grid represents opportunities for utilities and consumers to benefit from efficient management of energy and advanced equipment and devices. It offers significant opportunities to wisely manage the nation's fuel resources by potentially reducing the national need for additional generation sources, better integrating renewable and non-renewable generation sources into the grid's operations, reducing outages and cascading problems, and enabling consumers to better manage their energy consumption. DOE has to opportunity to address many of these challenges and accelerate the deployment schedule so that the nation can achieve the many benefits a Smart Grid offers.

[37] Rick Nicholson and others, *Impact of the Financial Crisis on Technology Spending in the Utility Industry* (Framingham, MA: Energy Insights, October 17, 2008).

[38] Rick Nicholson and others, *Impact of the Financial Crisis on Technology Spending in the Utility Industry* (Framingham, MA: Energy Insights, October 17, 2008).

Chapter 4
Recommendations

Considering the importance of a Smart Grid, the Electricity Advisory Committee (EAC) finds that it is in the best interest of the nation to accelerate the deployment of cost-effective Smart Grid technologies. A Smart Grid can be a mechanism for achieving the nation's goals in the areas of energy security, climate change, grid reliability, and economic growth.

At the same time, there are serious challenges to the timely development of a Smart Grid. Accordingly, the EAC offers the following recommendations to DOE:

1. Develop a roadmap by December 2009 for the achievement of a nationwide Smart Grid. The key elements of this roadmap should include:
   - A description of the essential components of the Smart Grid
   - A prioritization for the development of these components
   - Identification of Smart Grid subsectors that particularly need further investment
   - A timetable for Smart Grid investments necessary by utilities and other stakeholders throughout the United States
   - Identification of the areas in the electric grid that need to be able to interact seamlessly
2. Develop, manage, conduct, and communicate appropriate research and development projects to identify and prove next steps, consistent with the roadmap, and direct the Smart Grid Regional Demonstration Initiative and Matching Grant Program as authorized in Section 1304 of the Energy Independence and Security Act of 2007.
3. Request that Congress appropriate the funds needed for the Smart Grid Regional Demonstration Initiative and the Smart Grid Investment Matching Grant Program. Also, request that Congress provide the National Institute of Standards and Technology (NIST) with the funds to coordinate the development of a framework that includes protocols and model standards for information management; this will help achieve interoperability of Smart Grid devices and systems[39] as defined in Section 1305 of the Energy Independence and Security Act of 2007.
4. Create a Smart Grid Program Office to facilitate implementation of the Smart Grid roadmap. This DOE program should do the following:
   - Act as a clearinghouse of global Smart Grid information via web-based self-service tools.
   - Provide information on best practices, technical assistance, infrastructure plans, etc.
   - Develop and make available educational materials to state utility regulators, utilities, consumer advocates, and other stakeholders.
   - Provide or support coordination of Smart Grid activities among diverse organizations, if appropriate.
   - Drive standards-based work once NIST completes its assessment, called for in the Energy Independence and Security Act of 2007, by requiring utilities to report and publish comparative scores.

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5. Carry out a focused education campaign. The DOE campaign should focus on educating consumers on the cost of energy and how those costs can be better managed. It should also foster a workforce training/development program to help train Smart Grid engineers and technicians and it should approach land-grant universities for assistance in disseminating information about energy technologies, energy use, and energy management.

6. Work with Congress, industry, state regulators, and other stakeholders to create incentives that will drive a market for Smart Grid-ready appliances and other devices.

7. Leverage the Electricity Advisory Committee to serve as the Obama Administration's Grid Modernization Commission to facilitate the adoption of Smart Grid practices across the nation.

Appendix A
Acronyms

AC	alternating current
AMI	advanced metering infrastructure
AMR	automatic meter reading
AMS	advanced metering system
CAISO	California Independent System Operator
CIM	Common Information Model
CPUC	California Public Utilities Commission
DG	distributed generation
DOE	U.S. Department of Energy
DR	demand response
EAC	Electricity Advisory Committee
EPRI	Electric Power Research Institute
ESPP	Energy-Smart Pricing Plan
FACTS	flexible alternating current transmission systems
FLISR	Fault location, isolation, and service restoration
GPS	global positioning system
HAN	home area network
HVAC	heating, ventilation, and cooling
HVDC	high-voltage direct current
IED	intelligent electronic device
ISO	independent system operator
IT	information technology
kW	kilowatt
LTRA	*NERC Long-term Reliability Assessment*
MW	megawatts
MwH	megawatt hour
NETL	National Energy Technology Laboratory
NERC	North American Electric Reliability Corporation
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
OMS	outage management system
PHEV	plug-in hybrid electric vehicle
PUCT	Public Utilities Commission of Texas
SCADA	supervisory control and data acquisition
SG	Smart Grid
SOA	service-oriented architecture
SVC	Static Var Compensator
RTO	regional transmission operator
RTP	real-time pricing

T&D	transmission and distribution
TASE-2	Telecontrol Application Service Element 2
Tx	load tap changer
UCA	Utility Communications Architecture
WAM	wide-area measurment

Appendix B
Energy Independence and Security Act of 2007 Smart Grid Sections

Table B-1. Energy Independence and Security Act Title XIII Smart Grid Technologies

Title XIII Section	Description of Title XIII
SEC. 1304. Smart Grid Technology Research, Development, and Demonstration	
1304.(a).1	To develop advanced techniques for measuring peak load reductions and energy-efficiency savings from smart metering, demand response / load management, distributed generation, and electricity storage systems
1304.(a).2	To investigate means for demand response / load management, distributed generation, and storage to provide ancillary services
1304.(a).3	To conduct research to advance the use of wide-area measurement and control networks, including data mining, visualization, advanced computing, and secure and dependable communications in a highly-distributed environment
1304.(a).4	To test new reliability technologies, including those concerning communications network capabilities, in a grid control room environment against a representative set of local outage and wide area blackout scenarios
1304.(a).5	To identify communications network capacity needed to implement advanced technologies
1304.(a).6	To investigate the feasibility of a transition to time-of-use and real-time electricity pricing
1304.(a).7	To develop algorithms for use in electric transmission system software applications
1304.(a).8	To promote the use of underutilized electricity generation capacity in any substitution of electricity for liquid fuels in the transportation system of the United States
1304.(a).9	In consultation with the Federal Energy Regulatory Commission, to propose interconnection protocols to enable electric utilities to access electricity stored in vehicles to help meet peak demand loads
1304.(b).1	The Secretary shall establish a smart grid regional demonstration initiative (referred to in this subsection as the `Initiative') composed of demonstration projects specifically focused on advanced technologies for use in power grid sensing, communications, analysis, and power flow control. The Secretary shall seek to leverage existing smart grid deployments.
SEC. 1306. Federal Matching Fund for Smart Grid Investment Costs	
1306.(b).1	In the case of appliances covered for purposes of establishing energy conservation standards under part B of title III of the Energy Policy and Conservation Act of 1975 (42 U.S.C. 6291 et seq.), the documented expenditures incurred by a manufacturer of such appliances associated with purchasing or designing, creating the ability to manufacture, and manufacturing and installing for one calendar year, internal devices that allow the appliance to engage in Smart Grid functions.

Title XIII Section	Description of Title XIII
1306.(b).2	In the case of specialized electricity-using equipment, including motors and drivers, installed in industrial or commercial applications, the documented expenditures incurred by its owner or its manufacturer of installing devices or modifying that equipment to engage in Smart Grid functions.
1306.(b).3	In the case of transmission and distribution equipment fitted with monitoring and communications devices to enable smart grid functions, the documented expenditures incurred by the electric utility to purchase and install such monitoring and communications devices.
1306.(b).4	In the case of metering devices, sensors, control devices, and other devices integrated with and attached to an electric utility system or retail distributor or marketer of electricity that are capable of engaging in Smart Grid functions, the documented expenditures incurred by the electric utility, distributor, or marketer and its consumers to purchase and install such devices.
1306.(b).5	In the case of software that enables devices or computers to engage in Smart Grid functions, the documented purchase costs of the software.
1306.(b).6	In the case of entities that operate or coordinate operations of regional electric grids, the documented expenditures for purchasing and installing such equipment that allows Smart Grid functions to operate and be combined or coordinated among multiple electric utilities and between that region and other regions.
1306.(b).7	In the case of persons or entities other than electric utilities owning and operating a distributed electricity generator, the documented expenditures of enabling that generator to be monitored, controlled, or otherwise integrated into grid operations and electricity flows on the grid utilizing Smart Grid functions.
1306.(b).8	In the case of electric or hybrid-electric vehicles, the documented expenses for devices that allow the vehicle to engage in Smart Grid functions (but not the costs of electricity storage for the vehicle).
1306.(b).9	The documented expenditures related to purchasing and implementing Smart Grid functions in such other cases as the Secretary shall identify. In making such grants, the Secretary shall seek to reward innovation and early adaptation, even if success is not complete, rather than deployment of proven and commercially viable technologies.
Smart Grid Functions—The Term "Smart Grid Functions" Means Any of the Following:	
1306.(d).1	The ability to develop, store, send and receive digital information concerning electricity use, costs, prices, time of use, nature of use, storage, or other information relevant to device, grid, or utility operations, to or from or by means of the electric utility system, through one or a combination of devices and technologies.
1306.(d).2	The ability to develop, store, send and receive digital information concerning electricity use, costs, prices, time of use, nature of use, storage, or other information relevant to device, grid, or utility operations to or from a computer or other control device.
1306.(d).3	The ability to measure or monitor electricity use as a function of time of day, power quality characteristics such as voltage level, current, cycles per second, or source or type of generation and to store, synthesize or report that information by digital means.
1306.(d).4	The ability to sense and localize disruptions or changes in power flows on the grid and communicate such information instantaneously and automatically for purposes of enabling automatic protective responses to sustain reliability and security of grid operations.
1306.(d).5	The ability to detect, prevent, communicate with regard to, respond to, or recover from system security threats, including cyber-security threats and terrorism, using digital information, media, and devices.
1306.(d).6	The ability of any appliance or machine to respond to such signals, measurements, or communications automatically or in a manner programmed by its owner or operator without independent human intervention.
1306.(d).7	The ability to use digital information to operate functionalities on the electric utility grid that were previously electro-mechanical or manual.
1306.(d).8	The ability to use digital controls to manage and modify electricity demand, enable congestion management, assist in voltage control, provide operating reserves, and provide frequency regulation.
1306.(d).9	Such other functions as the Secretary may identify as being necessary or useful to the operation of a Smart Grid.

Source: ABB.[40]

[40] Table for this report created by ABB.

Table B-2. Smart Grid Technologies and Their Applicability under Title XIII

Technologies	Total checks	Title XIII Sections: R&D and Demonstrations (50% match)										Investment Match (20% match)									Smart Grid Functions								
		1304.(a).1	1304.(a).2	1304.(a).3	1304.(a).4	1304.(a).5	1304.(a).6	1304.(a).7	1304.(a).8	1304.(a).9	1304.(b).1	1306.(b).1	1306.(b).2	1306.(b).3	1306.(b).4	1306.(b).5	1306.(b).6	1306.(b).7	1306.(b).8	1306.(b).9	1306.(d).1	1306.(d).2	1306.(d).3	1306.(d).4	1306.(d).5	1306.(d).6	1306.(d).7	1306.(d).8	1306.(d).9
		Sensors, Measuring	DR, DG, storage -> ancillary services	Wide-area measurement (WAM), control network, data mining, visualization,	Reliability technologies	Communication network cap	Transition to time-of-use and real-time pricing	Algorithms for transmission system software	Electric vehicle	Electricity stored in vehicles	Regional demo	Appliances to engage in Smart Grid (SG) functions	Motor and drive	T&D equipment fitted with smarts	Metering, sensors, control devices --> SG	Software enables devices and computer --> SG	Regional grid operations	Distibuted generation (DG)	Electric or hybrid vehicles	Smarts by secretary	Metering	Communication	Reporting	Fault location, isolation, and restoration service (FLISR)	Security	Automatic control	Digitizing	Use digital control to manage grid	Catch all
		18	9	26	34	2	12	10	2	1	0	6	1	11	29	27	9	4	2	1	15	11	16	27	3	27	15	26	1
Smart Grid Technologies																													
Enables Active Participation by Consumers																													
Smart meters	5	X					X								X						X	X							
Advanced metering infrastructure	7	X					X					X			X						X	X						X	
Upgrade existing automatic meter reading (AMR; one-way) technology to advanced metering infrastructure (AMI; two-ways)	7	X					X					X			X						X	X						X	
Programmable communicating thermostat	2						X																			X			
Smart Home software --> enable home owners to self-manage	3											X				X										X			
Home automation network interfaced with utility Smart Grid system	7	X					X								X						X	X	X			X			
Building/facility energy management system interfaced with market pricing signal and/or utility Smart Grid system	10	X	X				X								X	X					X	X	X			X		X	
Accommodates All Generation and Storage Options																													
Virtual utilities (integrated DG with load management)	5		X				X										X	X								X			
Plug-in hybrid electric vehicles	3								X	X									X										
Solar/wind generation	2		X															X											
Distributed energy resource management system (software to optimize DG and renewable energy operations)	5		X													X		X								X		X	
Energy storage devices/systems	2		X															X											
Enables New Products, Services, and Markets																													
Real-time/time-of-use pricing options design and research	2						X										X												
New market system (applying intelligent network feedbacks and consumer responses)	8			X	X		X	X							X		X										X	X	

Technologies	Total checks	Title XIII Sections																												
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		1304.(a).1	1304.(a).2	1304.(a).3	1304.(a).4	1304.(a).5	1304.(a).6	1304.(a).7	1304.(a).8	1304.(a).9	1304.(b).1	1306.(b).1	1306.(b).2	1306.(b).3	1306.(b).4	1306.(b).5	1306.(b).6	1306.(b).7	1306.(b).8	1306.(b).9	1306.(d).1	1306.(d).2	1306.(d).3	1306.(d).4	1306.(d).5	1306.(d).6	1306.(d).7	1306.(d).8	1306.(d).9
		Sensors, Measuring	DR, DG, storage -> ancillary services	Wide-area measurement (WAM), control network, data mining, visualization,	Reliability technologies	Communication network cap	Transition to time-of-use and real-time pricing	Algorithms for transmission system software	Electric vehicle	Electricity stored in vehicles	Regional demo	Appliances to engage in Smart Grid (SG) functions	Motor and drive	T&D equipment fitted with smarts	Metering, sensors, control devices --> SG	Software enables devices and computer --> SG	Regional grid operations	Distibuted generation (DG)	Electric or hybrid vehicles	Smarts by secretary	Metering	Communication	Reporting	Fault location, isolation, and restoration service (FLISR)	Security	Automatic control	Digitizing	Use digital control to manage grid	Catch all
		18	9	26	34	2	12	10	2	1	0	6	1	11	29	27	9	4	2	1	15	11	16	27	3	27	15	26	1
Smart Grid Technologies																													
Demand response / load management program	7		X				X					X					X				X	X				X			
Appliances interface with utility Smart Grid system	1											X																	
Motor and drives interface with utility Smart Grid system	1												X																
Provides Power Quality for the Range of Needs in a Digital Economy																													
Smart sensors (sensors with communication and local smarts)	7	X												X	X						X	X		X			X		
Intelligent electronic devices (IEDs)	11	X												X	X	X					X	X	X	X		X	X	X	
Smart switches capable of communications	6			X										X	X									X		X	X		
Smart reclosers with communications capability	7			X	X									X	X									X		X	X		
Intelligent assets with built-in communcations (smart transformer, breakers)	3													X												X	X		
Load tap changer on load tap changer (Tx) (voltage controls with communitcation cap)	8			X	X									X	X									X		X	X	X	
Add-on to distribution automation utilizing existing AMI communication infrastructure	6			X	X									X										X		X	X		
Smart feeder automation (microprocessor based with communication capability)	9	X		X	X			X							X	X								X		X	X		
Upgrade and replace existing electro-mechanical control system with microprocessor-based control system with communication capability	6				X									X	X									X		X	X		
Interconnection protocols (electric vehicles, storage)	4		X						X										X							X			
System interoperability adoption project	2																										X	X	
Optimizes Asset Utilization and Operating Efficiency																													
Condition-based monitoring/maintenance	3				X																		X					X	
Computerized maintenance management	5				X			X								X							X				X		
Advanced asset management software	4				X											X							X	X					

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		Sensors, Measuring	DR, DG, storage -> ancillary services	Wide-area measurement (WAM), control network, data mining, visualization,	Reliability technologies	Communication network cap	Transition to time-of-use and real-time pricing	Algorithms for transmission system software	Electric vehicle	Electricity stored in vehicles	Regional demo	Appliances to engage in Smart Grid (SG) functions	Motor and drive	T&D equipment fitted with smarts	Metering, sensors, control devices --> SG	Software enables devices and computer --> SG	Regional grid operations	Distibuted generation (DG)	Electric or hybrid vehicles	Smarts by secretary	Metering	Communication	Reporting	Fault location, isolation, and restoration service (FLISR)	Security	Automatic control	Digitizing	Use digital control to manage grid	Catch all
		18	9	26	34	2	12	10	2	1	0	6	1	11	29	27	9	4	2	1	15	11	16	27	3	27	15	26	1
Smart Grid Technologies																													
Advanced outage avoidance and management	9			X	X			X								X	X						X	X	X	X			
Dynamic line rating to improve system reliability	9			X	X			X							X	X	X						X	X				X	
Transformer load management	6			X	X			X								X							X					X	
Grid simulator and modeler—a sandbox for what-if learning	7			X	X			X								X	X						X					X	
Flexible power flow control (FACTS, SVC, HVDC) to improve power grid performance under disturbances	8	X		X	X										X	X	X									X		X	
Process re-engineering using intelligent system	3				X															X									X
Addresses and Responds to System Disturbances in a Self-Healing Manner																													
Operation Centers																													
Optimized Volt/Var management system (algorithm with communication and controls)	7			X	X										X	X								X		X		X	
Integrated outage management system (OMS) and AMI	4			X	X											X								X					
Integrated OMS and work management system	3				X											X								X					
Outage damage assessment for restoration	6			X	X			X								X							X	X					
Distribution state estimator	5			X	X											X							X	X					
Fault location and analysis	5			X	X											X							X	X					
Fault management (reconfiguration and restoration)	4			X	X											X								X					
Wide area monitoring system (a system monitoring center with GPS-synchronized phasor measurement units)	13	X		X	X	X		X							X	X	X				X	X	X		X			X	
Load management	5		X	X											X											X		X	
Substation Automation																													
Substation automation solution with 61850 interoperable protocol	8			X		X									X	X					X	X				X		X	
Station equipment condition and reliability monitoring (with communication)	7			X	X										X	X					X		X					X	

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Smart Grid Technologies																													
Fault indicators/recorders	5	X												X							X			X			X		
Feeder and Distribution Automation																													
Smart feeder automation (microprocessor based with communication capability)	10	X		X	X										X	X					X	X		X		X		X	
Feeder condition monitoring to improve reliability	6	X		X	X										X						X		X						
Automated adaptive relaying	6	X			X										X									X		X		X	
Feeder load transfer load/switch for demand response / load management	9	X	X	X			X								X	X					X					X		X	
Automated feeder reconfiguration for loss reduction, overload relief	7	X		X	X										X									X		X		X	
Feeder fault detection and diagnostics	7	X		X	X										X	X								X				X	
Feeder equipment failure detection	5	X			X										X									X				X	
Voltage regulator with communication capability	7				X									X	X									X		X	X	X	
Capacitor control with communication capability	7				X									X	X									X		X	X	X	
Operates Resiliently Against Physical and Cyber Attacks and Natural Disasters																													
Cyber-security and data integrity	4				X							X				X									X				
Weather prediction and storm damage forecast and OMS	4				X			X								X								X					